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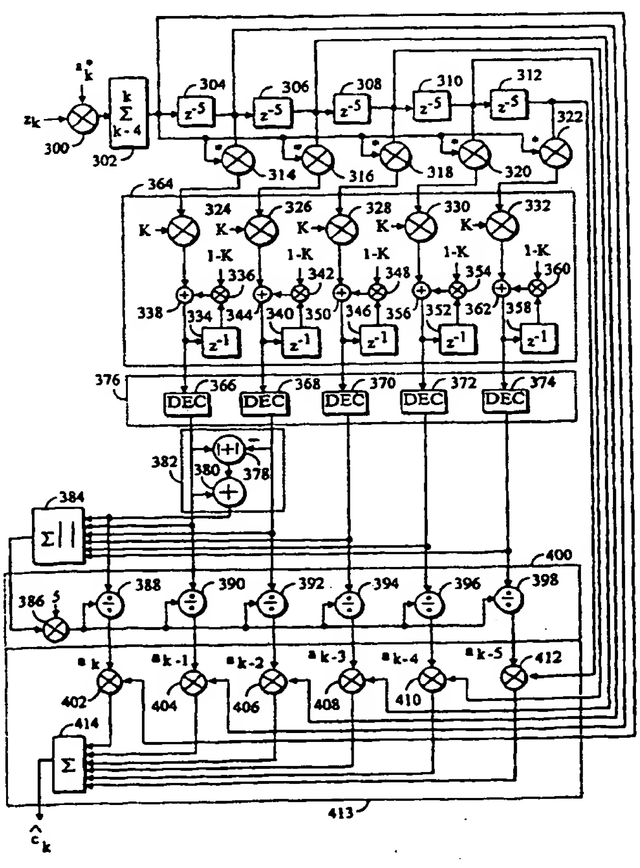
(54) Title: METHOD OF FORMING CHANNEL ESTIMATE, AND RECEIVER

(57) Abstract

The invention relates to a channel estimation method and a receiver for forming a channel estimate. The arrangement according to the invention comprises forming a preliminary channel estimate c_k by multiplying a received sample z_k by a known pilot symbol in a multiplier (300); forming a preliminary autocorrelation of preliminary channel estimates that are successive in time in multipliers (314 – 322); filtering preliminary autocorrelations by averaging in a filter (364), and forming filter parameters α_k to α_{k-m} in a filter (401) on the basis of the averaged autocorrelation, and forming an average channel estimate by a filter section (413) which forms a channel estimate and which is controlled by filter parameters α_k to α_{k-m}.



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METHOD OF FORMING CHANNEL ESTIMATE, AND RECEIVER

FIELD OF THE INVENTION

The invention relates to formation of a channel estimate in a radio system comprising at least one base station and several terminal equipments.

BACKGROUND OF THE INVENTION

In a CDMA system, a base station or a terminal equipment operating as a receiver employs several channel estimation arrangements. However, channel estimates are usually filtered by a simple low-pass filter. The filter bandwidth is selected according to the maximum Doppler frequency. One of the problems of such a prior art arrangement is that the channel estimator has poor performance at low Doppler frequencies. Furthermore, such a channel estimator does not operate in a reliable manner if the power spectrum is clearly asymmetrical.

An optimum channel estimator could be implemented by the Wiener filter if the channel autocorrelation and the noise power spectral density were known. In practice they are not known but must be estimated. The implementation of the optimum Wiener filter in an actual receiver is further complicated by the elaborate matrix operations it requires and by errors in parameter estimation. In known adaptive channel estimators adaptivity is achieved by means of LMS (Least Mean Square), RLS (Recursive Least Squares) or Kalman algorithms. The LMS and RLS arrangements are disclosed in greater detail in the following publications: A. Mämmelä, V-P. Kaasila, Prediction, *Smoothing and Interpolation In Adaptive Diversity Reception*, ISSSTA'94, pp 475 - 478; S. Mclughlin, B. Mulgrew, C. F. N. Cowan, *Performance Comparison of Least Squares and Least Mean Squares Algorithms as HF Channel Estimators*, ICASSP'87, pp 2105 - 2108; A. P. Clark, S. G. Jayasinghe, *Channel Estimation for Land Mobile Radio Systems*, IEE Proceedings, Vol 134, Pt. F, No 4, July 1987, pp 383 - 393; A. P. Clark, F. McVerry, *Improved Channel Estimator for an HF Radio Link*, Signal Processing, Vol 5, No 3, May 1983, pp 241 - 255; A. P. Clark, F. McVerry, *Channel Estimation for an HF Radio Link*, IEE Proceedings, Vol 128, Pt. F, No 1, February 1981, pp 33 - 42; and A. P. Clark, S. Harihan, *Adaptive Channel Estimator for an HF Radio Link*, IEEE Transactions on Communications, Vol 37, No 9, September 1989, pp 918 - 926, which will be incorporated herein by reference.

The following publications: A. P. Clark, R. Harun, *Assessment of Kalman-filter Channel Estimators for an HF Radio Link*, IEE Proceedings, Vol 133, Pt. F, No 6, October 1986, pp 513 - 521; H. H. Clayton, P. Fines, A. H. Aghvami, *Carrier Synchronization Using Kalman Filters for Dynamic Doppler Shift Environments*, PIMRC'93, B2.7; S. A. Fechtel, H. Meyr, *An Investigation of Channel Estimation and Equalization Techniques for Moderately Rapid Fading HF-Channels*, ICC'91, pp 768 - 772; and S. Harihan, A. P. Clark, *HF Channel Estimation Using Fast Transversal Filter Algorithm*, IEEE Transactions on Acoustics, Speech, and Signal Processing, Vol 38. No 8, August 1990, pp 1353 - 1362, which will be incorporated herein by reference, describe the use of the Kalman filter in channel estimation.

The LMS and RLS algorithms have poor performance and they are not designed to operate at low or strongly negative signal-to-noise ratios. They are thus not suitable for a CDMA receiver. A problem with the adaptive Kalman algorithm is that it is complicated. Kalman algorithms, which adapt to the Doppler power spectrum and change their performance degree number, are too complicated for a practical application.

BRIEF DESCRIPTION OF THE INVENTION

An object of the invention is to provide a method and a receiver implementing the method so as to solve the aforementioned problems. This is achieved by a channel estimation method used in a CDMA radio system comprising at least one base station and several terminal equipments, which communicate with each other by transmitting and receiving signals, in which method a received signal is sampled and a pilot signal comprising pilot symbols is transmitted. The method according to the invention further comprises forming a preliminary channel estimate by multiplying a received sample by a known complex conjugate of a pilot symbol; forming a preliminary autocorrelation of preliminary channel estimates that are successive in time; filtering preliminary autocorrelations by averaging, and forming a filter parameter for filtration of an average channel estimate on the basis of the averaged autocorrelation; and forming an average channel estimate by channel estimate filtration, which is controlled by filter parameters.

The invention also relates to a receiver in a radio system comprising at least one base station and several terminal equipments, which comprise a transmitter and a receiver and which communicate with each other by transmitting and receiving signals including a pilot signal which comprises pilot

symbols, the receiver being arranged to sample a received signal. The receiver is further arranged to form a preliminary channel estimate by multiplying a received sample by a known complex conjugate of a pilot symbol; to form a preliminary autocorrelation of preliminary channel estimates that are successive in time; to filter preliminary autocorrelations by averaging; to form a filter parameter for filtration of a channel estimate on the basis of the averaged autocorrelation; and to form an average channel estimate by channel estimate filtration which is arranged to be controlled by filter parameters.

The preferred embodiments of the invention are disclosed in the dependent claims.

The basic idea of the invention is that filter parameters or weighting coefficients of a channel filter are formed directly from autocorrelation functions of the channel estimates.

The method and the system according to the invention provide several advantages. Filter parameters are formed directly from the autocorrelation functions of the channel estimates with only a small amount of calculation and without complicated LMS, RLS or Kalman calculation operations for predicting the estimation error. Furthermore, since the channel estimator arrangement according to the invention does not utilize any prior data about the process to be estimated, the arrangement provides good performance for example with a clearly asymmetrical power spectrum. The arrangement according to the invention is also reliable at low signal-to-noise ratios.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described below in greater detail by means of the preferred embodiments with reference to the accompanying drawings, in which

Figure 1 is a block diagram of a predictive channel estimate filter,

Figure 2 is a block diagram of a filter for calculating filter parameters in a channel estimate filter,

Figure 3 is a block diagram of a predictive channel estimate filter according to the invention,

Figure 4 shows a smoother-type channel estimate filter, which receives eight pilot symbols in one time slot from a control channel,

Figure 5 shows a filter for calculating filter parameters, which receives eight pilot symbols in one time slot from a control channel,

Figure 6 shows a smoother-type channel estimate filter, which receives four pilot symbols twice in one time slot from a control channel,

Figure 7 shows a filter for calculating filter parameters, which receives four pilot symbols twice in one time slot from a control channel, and

Figure 8 is a block diagram of a RAKE receiver.

DETAILED DESCRIPTION OF THE INVENTION

The arrangement according to the invention is applicable particularly in a CDMA radio system, without being restricted thereto, however.

A radio system comprises at least one base station and several terminal equipments, which are usually mobile phones. A base station and a terminal equipment communicate with one another by transmitting and receiving for example a data signal and a pilot signal. A data signal usually consists of speech or other user data. A base station transmits on a control channel a pilot signal which is used in power control and synchronization. Signals comprise symbols, which can be presented and processed in a real or complex form. Symbols represent bits or bit combinations. Particularly in a CDMA radio system a signal propagates from the base station to a terminal equipment via several paths, and the signal components arrive at the receiver with different time delays.

Let us first examine an arrangement shown in Figures 1 and 2, which illustrates the principle of the invention. Figure 1 shows a channel estimate filter which is based on a finite impulse response (FIR) filter. An incoming received signal sample z_k, which corresponds to a digital symbol, is multiplied in a multiplier 100 by a complex conjugate a_k^* of a pilot symbol, which is a digital symbol that can be presented as a bit or a bit combination. The pilot symbol a_k is known in advance. The received sample z_k can be given in form $z_k = a_k \cdot c_k + n_k$, and z_k can be multiplied by the complex conjugate of the pilot symbol to provide $z_k \cdot a_k^* = c_k + n_k$, where n_k represents noise. If real symbols are used, the complex conjugate does not naturally change the symbol in any way. The multiplication provides a preliminary channel estimate c_k, which is delayed in every delay block 102 to 104 for a time corresponding to one symbol (the delay of one sample/symbol as a Z transformation can be denoted by z^{-1}). The number of the delay blocks 102 to 104 is selected freely so as to cover a particular delay area. Each preliminary

channel estimate c_k to c_{k-m} is multiplied by a filter parameter α_k to α_{k-m} in multipliers 106 to 110. The filter parameters α_k to α_{k-m} weight the preliminary channel estimates c_k to c_{k-m}. The weighted channel estimates are added together in a block 112 to provide an averaged channel estimate.

Figure 2 shows a block diagram of a filter for calculating filter parameters α_k to α_{k-m} in a channel estimate filter, i.e. a filter parameter filter. Also in this arrangement a received sample z_k is multiplied by the complex conjugate of the pilot symbol a_k in a multiplier 200 and delayed in delay blocks 202 to 206, similarly as in Figure 1. The obtained preliminary channel estimates c_k to c_{k-m} are correlated with a first preliminary channel estimate c_k in blocks 208 to 212, which are preferably multipliers. Even though it is not necessary, at this stage the preliminary correlation results can be scaled or normalized for example such that each preliminary correlation is divided by the sum of all the preliminary correlations (such scaling or normalization is not shown in Figure 2). Subsequently each preliminary autocorrelation result is multiplied by a forgetting factor K in multipliers 214 to 218, which are part of an averaging filter section 238. Let us examine below in greater detail the preliminary autocorrelation result $\hat{\vartheta}_{k,1}$. The autocorrelation result $\hat{\vartheta}_{k,1}$ is obtained by $\hat{\vartheta}_{k,1} = c_k \cdot c_{k-1}^{*}$, wherein i is index i = 1, ...m, and subindex 1 denotes the first path l = 1. The correlation result $\hat{\vartheta}_{k,1}$ proceeds to the filter section 238, where the autocorrelation is averaged by taking into account a finite or infinite number of correlation results $\hat{\vartheta}_{k,1}$. With the IIR (Infinite Impulse Response) filter shown in Figure 2 the averaging is infinite (corresponds to infinite integration), whereas with the FIR filter the averaging would be finite (corresponding to integration from a particular moment in time to some other moment). The correlation result is first multiplied by the forgetting factor K, which has a value smaller than 1, for example between 0.001 and 0.01. Subsequently, the correlation result $(1-K)\cdot\hat{\rho}_{k,1,i}(t-1)$, which has already been filtered and weighted, is added in an adder 224 to the correlation result. The former correlation result has been obtained by delaying the correlation result in a delay block 220 and by multiplying the delayed correlation result by factor 1 - K in a multiplier 222. Filter parameter α_k is thus obtained from the

averaged correlation result $\hat{\rho}_{k,1,i} = (1-K)\cdot\hat{\rho}_{k,1,i}(t-1) + K\cdot\hat{\vartheta}_{k,1}(i)$. Filter parameter α_k can be identical with the filtered correlation $\alpha_k = \hat{\rho}_{k,1,i}$, but the filter parameter is more often a function of the filtered correlation $\alpha_k = f(\hat{\rho}_{k,1,i})$. The other filter parameters α_{k-1} to α_{k-m} are obtained correspondingly in blocks 226 to 232. In the arrangement of Figure 2, filter parameters are formed specifically for each pilot symbol in each received sample, wherefore the more delay elements 102 to 104, and 202 to 206, and thus preliminary channel estimates are being used, the more complicated it is to form the filter parameters α_k to α_{k-m}.

The calculation of the filter parameters α_k to α_{k-m} has been simplified in the arrangement according to the invention by combining several received samples z_k and by thus calculating the filter parameters α_k to α_{k-m} less often. Such less frequent formation of the filter parameters α_k to α_{k-m} is shown in Figure 3, where the process begins similarly as in Figures 1 and 2 by multiplying a received sample z_k by the complex conjugate a_k^* of the pilot symbol in a multiplier 300. The number of the preliminary channel estimates c_k is thereafter decreased for example by 5, as shown in Figure 3, by means of for instance averaging, which improves the signal-to-noise ratio. Delay blocks 304 to 312 thereafter delay the preliminary channel estimates at intervals of 5 symbols (as a Z transformation z^{-5}). The delayed channel estimates are subjected in multipliers 314 to 322 to preliminary autocorrelation for path l, i.e. $\hat{\vartheta}_{k,1}, \hat{\vartheta}_{k-1,1}, \hat{\vartheta}_{k-2,1}, \ldots, \hat{\vartheta}_{k-m,1}$, wherein m is the number of the delayed preliminary channel coefficients, similarly as in Figures 1 and 2. Each preliminary autocorrelation $\hat{\vartheta}_{k,1}, \hat{\vartheta}_{k-1,1}, \hat{\vartheta}_{k-2,1}, \ldots, \hat{\vartheta}_{k-m,1}$ is filtered by finite or infinite averaging filtration in a filter section 364. Figure 3 shows an IIR filter 364. Each preliminary autocorrelation $\hat{\vartheta}_{k,1}, \hat{\vartheta}_{k-1,1}, \hat{\vartheta}_{k-2,1}, \ldots, \hat{\vartheta}_{k-m,1}$ is multiplied by factor K in multipliers 324 to 332. For example, to the preliminary correlation result $\hat{\vartheta}_{k-1,1}$ is added in an adder 344 the correlation result $(1-K)\cdot\hat{\rho}_{k-1,1,i}(t-1)$, which has already been filtered and weighted, and which has been obtained by delaying the correlation result in a delay block 340 and

by multiplying the delayed correlation result by factor 1 - K in a multiplier 342. The correlation results $\hat{\rho}_{k,1}, \hat{\rho}_{k-1,1}, \hat{\rho}_{k-2,1}, \ldots, \hat{\rho}_{k-m,1}$ which have been averaged by filtration thereafter proceed to a filter block 401, where the averaged correlation results $\hat{\rho}_{k,1}, \hat{\rho}_{k-1,1}, \hat{\rho}_{k-2,1}, \ldots, \hat{\rho}_{k-m,1}$ are decimated in a decimation block 376, the number of decimators 366 to 374 in the block being equal to the number of the delay blocks 304 to 312. Excessive sampling is thus reduced by using the decimators 366 to 374. Since an autocorrelation result cannot be formed for the latest symbol (symbol k) in the aforementioned blocks, this autocorrelation result is extrapolated from the earlier results in a block 382. Extrapolation is carried out for example by first calculating the absolute value difference between the two latest decimated correlation results $\left|\hat{\rho}_{k,1,1}(t) - \hat{\rho}_{k,1,2}(t)\right|$ in a block 380, whereafter the obtained result $\left|\hat{\rho}_{k,1,1}(t) - \hat{\rho}_{k,1,2}(t)\right|$ and the latest decimated correlation result $\hat{\rho}_{k,1,1}(t)$ are added together to form an absolute value sum $\left|\hat{\rho}_{k,1,1}(t) + \left|\hat{\rho}_{k,1,1}(t) - \hat{\rho}_{k,1,2}(t)\right|\right|$ in the block 380. Subsequently the decimated correlation results are added together and an absolute value of the sum is formed in an adder block 384.

In a scaling block 400, which replaces the scaling of the preliminary correlations before the IIR filter, the results which have been added together are first multiplied in a multiplier 386 by the number of symbol summations, which in this case is 5. Each decimated correlation result $\hat{\rho}_{k,1}, \hat{\rho}_{k-1,1}, \hat{\rho}_{k-2,1}, \ldots, \hat{\rho}_{k-m,1}$ is divided in division blocks 388 to 398 by a sum result $5\sum_{i=0}^{M}\left|\hat{\rho}_{k,1,i}(t)\right|$, where M is the number of the correlation results to be added together (in this example 6), in order to obtain filter parameters α_k to α_{k-m}. This can be presented as follows: $\alpha_{k,l}(i) = \dfrac{\hat{\rho}_{k,l,i(t)}}{5\sum_{i=0}^{M}\left|\hat{\rho}_{k,l,i}(t)\right|}$. However, in a practical application it is possible not to calculate at all the term $5\sum_{i=0}^{M}\left|\hat{\rho}_{k,1,i}(t)\right|$ in the divisor and not to perform the division, since it is sufficient to use a

decimated correlation result $\hat{\rho}_{k,l}, \hat{\rho}_{k-1,l}, \hat{\rho}_{k-2,l}, \ldots, \hat{\rho}_{k-m,l}$ either directly as the filter parameter α_k to α_{k-m}, or the filter parameter $\hat{\rho}_{k,l}, \hat{\rho}_{k-1,l}, \hat{\rho}_{k-2,l}, \ldots, \hat{\rho}_{k-m,l}$ can be scaled by a suitable number. The scaling block 400 is thus not absolutely necessary, or it can be replaced with multiplication by a constant.

When the filter parameters α_k to α_{k-m} have been formed, they proceed to a filter section (413), which forms the channel estimate, and the preliminary channel coefficients c_k to c_{k-m} are multiplied by the filter parameters α_k to α_{k-m} in multipliers 402 to 412. The results of the multiplication are thereafter added together in an adder 414, as shown in the example of Figure 1, in order to form an adaptive channel estimate $\hat{c}_k$. This can be presented as follows: $\hat{c}_{k,l} = \sum_{i=0}^{M} \alpha_{k,l}(i) \cdot \hat{c}_{k-i,l}$.

Figures 4 and 5 show an arrangement where the rate at which channel estimates are formed is decreased to one tenth, i.e. only one averaged channel estimate is calculated for all the ten symbols in a time slot. Symbol-specific channel estimates are interpolated from the formed time-slot-specific averaged channel estimates. Furthermore, Figures 4 and 5 show the operation of the arrangement according to the invention in a case where all the symbols in a control channel time slot are not pilot symbols. Figures 4 and 5 show calculation of a channel estimate from seven time slots by way of example. Figure 4 shows a channel estimator filter. In the arrangement according to the invention the number of time slots can be selected freely. Time slot 420, which comprises ten symbols, has eight pilot symbols 422 and two other symbols 424. Time slot 426 comprises eight pilot symbols 428 and two other symbols 430. Time slot 432 comprises eight pilot symbols 434 and two other symbols 436. Time slot 438 comprises eight pilot symbols 440 and two other symbols 442. Time slot 444 comprises eight pilot symbols 446 and two other symbols 448. Time slot 450 comprises eight pilot symbols 452 and two other symbols 454. Only eight pilot symbols are shown from the last time slot 455. In blocks 456, 458, 460, 462, 464, 466 and 468, the received samples z_k are also multiplied by the corresponding complex conjugates a_k^* of the pilot symbols, as for example in block 100 of Figure 1. In this arrangement the products of each of the eighth pilot symbols 422, 428, 434, 440, 446, 452 and 455 and the received sample are subjected to smoother filtration for

example by adding the products together in respective adders 456, 458, 460, 462, 464, 466 and 468. The summation can also be performed by calculating an average where each symbol in the summation is weighted by a weighting coefficient that is of equal or different value. The obtained preliminary channel estimates c(s-3), c(s-2), c(s-1), c(s), c(s+1), c(s+2) and c(s+3) are weighted by filter parameters α(s-3), α(s-2), α(s-1), α(s), α(s+1), α(s+2) and α(s+3) by multiplication in multipliers 470 to 482. In this arrangement data processing is delayed by three time slots in order to provide filtration that is two-sided with respect to the data processing moment. The weighted channel estimates are added together in an adder 484 to obtain average channel estimates 486 to 490 which are successive in time. This means that when the filter arrangement shown in Figure 4 is in operation, one average channel estimate is continuously formed for each time slot. Between these average channel estimates it is possible to interpolate symbol-specific and sample-specific channel estimates 494 by a linear interpolator 498 in the arrangement according to the invention.

The filter parameters α(s-3), α(s-2), α(s-1), α(s), α(s+1), α(s+2) and α(s+3) of the smoother channel estimator filter shown in Figure 4 are formed for example by a filter parameter filter shown in Figure 5. Similarly as in Figure 4, time slot 500 of Figure 5, which comprises ten symbols, has eight pilot symbols 502 and two other symbols 504. Time slot 506 comprises eight pilot symbols 508 and two other symbols 510. Time slot 512 comprises eight pilot symbols 514 and two other symbols 516. Time slot 518 comprises eight pilot symbols 520 and two other symbols 522. Time slot 524 comprises eight pilot symbols 526 and two other symbols 528. Time slot 530 comprises eight pilot symbols 532 and two other symbols 534. The latest time slot 536 comprises eight pilot symbols 538 and two other symbols 540. Instead of seven time slots, only the four latest time slots 518, 524, 530 and 536 are required for calculating the filter parameters. Smoother filters 542 to 554 operate similarly as the blocks 456 to 468 in Figure 4. The preliminary channel coefficients c(s-3), c(s-2) and c(s-1) are multiplied by a preliminary channel coefficient c(s) in multipliers 556 to 560 to obtain a preliminary correlation result $\hat{\vartheta}(s-3)$, $\hat{\vartheta}(s-2)$, $\hat{\vartheta}(s-1)$. The preliminary correlation results are filtered in IIR filters by weighting by factor K in multipliers 562 to 566, by adding to the preliminary correlation results in adders 572, 578, 584 the correlation results

$(1-K)\cdot\hat{\rho}_{s-3}(t-1)$, $(1-K)\cdot\hat{\rho}_{s-2}(t-1)$, $(1-K)\cdot\hat{\rho}_{s-1}(t-1)$, which have already been filtered and weighted, and which have been obtained by delaying the correlation results in delay blocks 568, 574, 580, and by multiplying the delayed correlation results by factor 1 - K in multipliers 570, 576, 582. The filtration provides filter parameters α(s-3), α(s-2), α(s-1). Filter parameter α(s) is formed from the filtered correlation results $\hat{\rho}_{s-2}$ and $\hat{\rho}_{s-1}$ by means of an absolute value sum $\left|\hat{\rho}_{s-1}+\left|\hat{\rho}_{s-1}-\hat{\rho}_{s-2}\right|\right|$, similarly as shown in Figure 3. The filter parameters α(s+1), α(s+2) and α(s+3) are preferably formed as complex conjugates of filter parameters α(s-3), α(s-2), α(s-1).

Figures 6 and 7 show an arrangement where the rate at which channel estimates are formed is decreased to one fifth. Figure 6 shows a similar channel estimator filter as Figure 4, except that in this case two channel coefficients 712 to 714 are formed in each time slot. This is important for a fast-moving terminal equipment since the estimation error increases significantly when approaching the Nyqvist limit. When only one channel estimate is formed per time slot, the Nyqvist limit is about 800 Hz if the duration of a time slot is about 0.625 ms. The Nyqvist limit corresponds to an approximate speed of 400 km/h. The products of four pilot symbols 600 to 626 and the received samples are combined twice per each time slot in smoother filters 628 to 654. Similarly as the arrangement shown in Figure 4, this arrangement is also based on smoother filtration where the signal processing is delayed by three time slots in order to provide time correlation that is two-sided (past - present) with respect to the signal processing moment. The preliminary channel coefficients of each time slot are multiplied in higher multipliers 656 to 680 by filter parameters α(b-6), α(b-5), α(b-4), α(b-3), α(b-2), α(b-1), α(b), α(b+1), α(b+2), α(b+3), α(b+4), α(b+5) and α(b+6), and in lower multipliers 684 to 708 correspondingly by filter parameters α(b-6), α(b-5), α(b-4), α(b-3), α(b-2), α(b-1), α(b), α(b+1), α(b+2), α(b+3), α(b+4), α(b+5) and α(b+6). After the higher multipliers 656 to 680 the products are added together in an adder 682, and after the lower multipliers 684 to 708 the products are added together in an adder 710 to obtain two channel estimates 712 per one time slot (in this case for the time slot comprising pilot symbols 612 and 614). Channel estimates for the time between these two channel estimates 712 are preferably formed by a linear interpolator 716. The interpolator 716 can also

be used to interpolate channel estimates between channel estimates 714 of the other time slots and the channel estimates 712 of the present time slot. Interpolated channel estimates are denoted by reference numeral 718.

Figure 7 shows a filter parameter filter which forms filter parameters $\alpha(b-6)$, $\alpha(b-5)$, $\alpha(b-4)$, $\alpha(b-3)$, $\alpha(b-2)$, $\alpha(b-1)$, $\alpha(b)$, $\alpha(b+1)$, $\alpha(b+2)$, $\alpha(b+3)$, $\alpha(b+4)$, $\alpha(b+5)$ and $\alpha(b+6)$ for the filter shown in Figure 6. This arrangement does not require all the seven time slots to be used, either. Four pilot symbols 720 to 734 are multiplied by the received samples, whereafter all the four products, which are preliminary channel coefficients, are added together in smoother filters 736 to 750. The channel coefficients related to each of the four pilot symbols 724, 728, 732 (excluding pilot symbols 720) are multiplied in higher multipliers 752 to 762 by a preliminary channel coefficient related to pilot symbols 734 in order to form a preliminary autocorrelation. In lower multipliers 764 to 774, the preliminary channel coefficients (excluding the preliminary channel coefficients related to pilot symbols 734) are multiplied by a channel coefficient related to pilot symbols 732 in order to provide a preliminary autocorrelation. The preliminary autocorrelations are thereafter added together in pairs in adders 776 to 786, and the preliminary autocorrelations which have been added together are subjected to IIR filtration in the manner described in the preceding figures by using weighting coefficient K in multipliers 788 to 798, by means of delaying in delay blocks 800, 806, 812, 818, 824 and 830, by using weighting coefficient 1 - K in multipliers 802, 808, 814, 820, 826 and 832, and by using summation in adders 804, 810, 816, 822, 828 and 834. Subsequently each averaged autocorrelation result is decimated in decimators 846, whereafter the decimated results proceed to block 848 for extrapolation (similarly as in block 382 in Figure 3) and for formation of the filter parameters $\alpha(b-6)$, $\alpha(b-5)$, $\alpha(b-4)$, $\alpha(b-3)$, $\alpha(b-2)$, $\alpha(b-1)$, $\alpha(b)$, $\alpha(b+1)$, $\alpha(b+2)$, $\alpha(b+3)$, $\alpha(b+4)$, $\alpha(b+5)$ and $\alpha(b+6)$. Groups of pilot symbols b -1 720 and b 722 are separated by four pilot symbols in time, whereas pilot symbols b + 1 724 and b 722 are separated by six pilot symbols in time. The procedure may be as shown in Figure 7. When at least two non-sample-specific averaged channel estimates are formed in each time slot, and the pilot symbols in a time slot form at least two symbol groups (e.g. b - 1, b and b + 1) which are separated in time by a different number of symbols from a pilot symbol group in the same time slot (4 symbols) and in a different time slot (6 symbols), the average autocorrelation of two successive averaged

autocorrelations with different distances in time is formed in the adders 776 to 786, and the time delay of the autocorrelation to the signal processing moment is adjusted to an average [(4 + 6)/2 = 5] of the distance of the aforementioned two pilot groups from the signal processing moment. This provides averaged correlation results $\rho(k-5)$, $\rho(k-10)$, $\rho(k-15)$, $\rho(k-20)$, $\rho(k-25)$, $\rho(k-30)$, which further require extrapolation ($\alpha(b)$), decimation and possibly scaling, as also shown in Figure 3. The averaged correlation results $\rho(k-5)$, $\rho(k-10)$, $\rho(k-15)$, $\rho(k-20)$, $\rho(k-25)$, $\rho(k-30)$ are used to form filter parameters $\alpha(b-6)$, $\alpha(b-5)$, $\alpha(b-4)$, $\alpha(b-3)$, $\alpha(b-2)$, $\alpha(b-1)$, $\alpha(b)$, $\alpha(b+1)$, $\alpha(b+2)$, $\alpha(b+3)$, $\alpha(b+4)$, $\alpha(b+5)$ and $\alpha(b+6)$ by scaling. Filter parameters $\alpha(b-6)$, $\alpha(b-5)$, $\alpha(b-4)$, $\alpha(b-3)$, $\alpha(b-2)$, $\alpha(b-1)$ [$\alpha(b+1)$, $\alpha(b+2)$, $\alpha(b+3)$, $\alpha(b+4)$, $\alpha(b+5)$ and $\alpha(b+6)$] can be used to form filter parameters $\alpha(b+1)$, $\alpha(b+2)$, $\alpha(b+3)$, $\alpha(b+4)$, $\alpha(b+5)$ and $\alpha(b+6)$ [$\alpha(b-6)$, $\alpha(b-5)$, $\alpha(b-4)$, $\alpha(b-3)$, $\alpha(b-2)$, $\alpha(b-1)$] as complex conjugates.

The channel estimator of Figures 6 and 7 can be presented mathematically as follows. A received sample $z_{k,l}$ is multiplied by a pilot symbol $a^*_{k,l}$ and integrated over four symbols in order to form a preliminary channel estimate $c_l(b)$, i.e. $c_l(b) = \frac{1}{4}\sum_{k-3}^{k} z_{k,l} \cdot a^*_{k,l}$, wherein k is the index of the pilot symbol, b is the time slot index, and l is the path index of a multipath-propagated signal. Two preliminary correlation vectors can be formed for one time slot by means of a preliminary channel estimate. If the latest time slot is denoted by index b, the following time correlation is obtained for the channel estimates:

$$\hat{\vartheta}_l(b) = c_l(b) \cdot [c_l(b-6)^* \; c_l(b-5)^* \; c_l(b-4)^* \; c_l(b-3)^* \; c_l(b-2)^* \; c_l(b-1)^*]$$

$$\hat{\vartheta}_l(b-1) = c_l(b-1) \cdot [c_l(b-7)^* \; c_l(b-6)^* \; c_l(b-5)^* \; c_l(b-4)^* \; c_l(b-3)^* \; c_l(b-2)^*].$$

In order to simplify the calculation of the correlation, the correlation vectors are added together before filtration in a 1-tap IIR filter, i.e. $\hat{\rho}_{l,1...6}(t) = (1-K) \cdot \hat{\rho}_{l,1...6}(t-1) + K \cdot (\hat{\vartheta}_l(b) + \hat{\vartheta}_l(b-1))$, wherein K is the forgetting factor of the IIR filter, $\hat{\vartheta}_l(b)$ is a preliminary correlation vector of the channel estimates for time slot b, and $\hat{\rho}_{l,1...6}(t)$ is the averaged correlation vector of the channel estimates at moment t. In order to extrapolate the

maximum correlation of the channel estimates (as in block 382 of Figure 3), the following product is formed: $\hat{\rho}_{1,7}(t) = \left|\hat{\rho}_{1,6}(t)\right| + \left\|\hat{\rho}_{1,6}(t)\right| - \left|\hat{\rho}_{1,5}(t)\right\|$.

Figure 8 shows a CDMA receiver comprising RAKE fingers. The receiver comprises an antenna 900 and RF means 902 which convert a signal received by the antenna 900 onto a baseband. The analog baseband signal is converted into a digital signal in an analog-to-digital converter 904. The digital signal proceeds to a RAKE block 914, where the delays of signal components that have propagated via different paths are first determined in a block 906. The signal thereafter propagates to RAKE fingers (comprising blocks 9062, 9064, 954 and 956), each of which is an independent receiver unit. The purpose of the RAKE fingers is to compose and demodulate one received signal component. Each RAKE finger is synchronized with a signal component which has propagated along an individual path, and in the CDMA receiver the signals from the receiver branches are combined in a combiner 912 to obtain a good-quality signal for decoding and other parts of the receiver (not shown in Figure 8). A signal arriving at a RAKE finger is despread in the block 9062, and the despread signal is integrated for the duration of one symbol in an integrator 9064 to form a sample z_k. A channel estimate $\hat{c}_k^*$ is formed in a block 952 by the method according to the invention. In a multiplier 956, the channel estimate $\hat{c}_k^*$ is multiplied by the sample z_k that was delayed in the delay block (the delay corresponds to the time required to form the channel estimate in the block 952) to provide a received symbol. This can be presented as follows: $z_k \cdot \hat{c}_k^* = (a_k \cdot c_k + n_k) \cdot \hat{c}_k^* = |c_k|^2 \cdot a_k + n_k$, where $|c_k|^2$ is the channel power, a_k is the symbol amplitude, and n_k is noise.

The arrangement according to the invention can be implemented most advantageously by means of microprocessors and a suitable program which executes the required process steps.

Even though the invention is described above with reference to an example according to the accompanying drawings, it is clear that the invention is not restricted thereto but it can be modified in several manners within the scope of the inventive idea disclosed in the appended claims.

CLAIMS

1. A channel estimation method used in a CDMA radio system comprising at least one base station and several terminal equipments, which communicate with each other by transmitting and receiving signals, in which method a received signal is sampled and a pilot signal comprising pilot symbols is transmitted, **characterized** by

forming a preliminary channel estimate by multiplying a received sample by a known complex conjugate of a pilot symbol;

forming a preliminary autocorrelation of preliminary channel estimates that are successive in time;

filtering preliminary autocorrelations by averaging, and forming a filter parameter for filtration of an average channel estimate on the basis of the averaged autocorrelation; and

forming an average channel estimate by channel estimate filtration, which is controlled by filter parameters.

2. A method according to claim 1, **characterized** by forming an average channel estimate by means of FIR-type channel estimate filtration, where preliminary channel estimates are delayed and weighted by filter parameters.

3. A method according to claim 1, **characterized** by forming filter parameters from preliminary autocorrelations by means of an IIR filter, which iteratively adds together successive preliminary autocorrelation results to provide an averaged autocorrelation result.

4. A method according to claim 1, **characterized** by forming filter parameters from preliminary autocorrelations by means of FIR filtration, where a predetermined number of autocorrelations are averaged.

5. A method according to claim 1, **characterized** by extrapolating the latest averaged autocorrelation from the previous averaged autocorrelations.

6. A method according to claim 1, **characterized** in that each filter parameter is directly an averaged autocorrelation.

7. A method according to claim 1, **characterized** by forming a filter parameter by scaling averaged autocorrelations.

8. A method according to claim 7, **characterized** by performing scaling by dividing an averaged autocorrelation by the sum of the averaged autocorrelations.

9. A method according to claim 1, **characterized** by forming filter parameters and averaged channel estimates less often than at intervals of one received sample by combining more than one preliminary sample-specific channel estimate into a single preliminary channel estimate, forming a filter parameter and an averaged channel estimate corresponding to the combined preliminary channel estimate, and estimating a sample-specific filter parameter and a channel estimate by interpolation.

10. A method according to claim 9, **characterized** by forming an averaged autocorrelation corresponding to the combined preliminary channel estimate, and decimating the averaged autocorrelations in order to form a filter parameter less often than at intervals of one received sample.

11. A method according to claim 10, **characterized** by decimating the averaged autocorrelations and, after decimation, extrapolating the latest averaged autocorrelation from the previous averaged autocorrelations.

12. A method according to claim 1, **characterized** by forming at least one channel estimate per time slot by using pilot symbols contained (422, 428, 434, 440, 446, 452, 455, 502, 508, 514, 520, 526, 532, 538) contained in the time slot when the symbols in the control channel time slot are only partly pilot symbols (422, 428, 434, 440, 446, 452, 455, 502, 508, 514, 520, 526, 532, 538), and by forming sample-specific averaged channel estimates by interpolation.

13. A method according to claim 1, **characterized** by forming at least two non-sample-specific averaged channel estimates in each time slot.

14. A method according to claim 13, **characterized** in that when pilot symbols in a time slot form at least two symbol groups with different distances in time from pilot symbol groups in the same and in an adjacent time slot, an average autocorrelation result of two successive averaged autocorrelations with different time distances is formed, and the time distance of the average autocorrelation result is adjusted to an average of the time distances of said two pilot groups.

15. A method according to claim 1, **characterized** by delaying the processing of the received signal by a predetermined time.

16. A method according to claim 15, **characterized** by delaying the processing of the received signal by a predetermined number of time slots, and by forming only the averaged channel estimates and the filter parameters that are later than/prior to the signal processing moment, and forming the filter parameters that are prior to/later than the signal processing moment as complex conjugates of the filter parameters that are later than/prior to the signal processing moment.

17. A method according to claim 1, **characterized** by receiving with a RAKE receiver, and the method being used to form an average channel estimate for each multipath-propagated signal.

18. A receiver in a radio system comprising at least one base station and several terminal equipments, which comprise a transmitter and a receiver and which communicate with each other by transmitting and receiving signals including a pilot signal which comprises pilot symbols, the receiver being arranged to sample a received signal, **characterized** in that the receiver is arranged

to form a preliminary channel estimate by multiplying a received sample by a known complex conjugate of a pilot symbol;

to form a preliminary autocorrelation of preliminary channel estimates that are successive in time;

to filter preliminary autocorrelations by averaging;

to form a filter parameter for filtration of a channel estimate on the basis of the averaged autocorrelation; and

to form an average channel estimate by channel estimate filtration which is arranged to be controlled by filter parameters.

19. A receiver according to claim 18, **characterized** in that the receiver is arranged to form an average channel estimate by means of an FIR-type channel estimate filter (120), which comprises delay elements (102 - 104, 304 - 312) for delaying preliminary channel estimates, and multipliers (106 - 110, 402 - 412) for weighting the preliminary channel estimates by filter parameters.

20. A receiver according to claim 18, **characterized** in that the receiver is arranged to form filter parameters from preliminary autocorrelations by means of an IIR filter (238, 364), which comprises an adder (224, 230, 236, 338, 344, 350, 356, 362, 572, 578, 584, 804, 816, 822,

828, 834) for iteratively adding together successive preliminary autocorrelation results in order to provide an averaged autocorrelation result.

21. A receiver according to claim 18, **characterized** in that the receiver is arranged to form filter parameters from preliminary autocorrelations by means of an FIR filter, where a predetermined number of preliminary autocorrelations are averaged.

22. A receiver according to claim 18, **characterized** in that the receiver is arranged to extrapolate the latest averaged autocorrelation from the previous averaged autocorrelations.

23. A receiver according to claim 18, **characterized** in that the receiver is arranged to form each filter parameter directly by means of the averaged autocorrelations.

24. A receiver according to claim 18, **characterized** in that the receiver is arranged to form a filter parameter by scaling the averaged autocorrelations.

25. A receiver according to claim 24, **characterized** in that the receiver is arranged to perform scaling by dividing an averaged autocorrelation by the sum of the averaged autocorrelations.

26. A receiver according to claim 18, **characterized** in that the receiver is arranged to form filter parameters and averaged channel estimates less often than at intervals of one received sample, such that the receiver is arranged to combine more than one sample-specific preliminary channel estimate into a single preliminary channel estimate, and the receiver is arranged to form a filter parameter and an averaged channel estimate corresponding to the combined preliminary channel estimate, and the receiver is arranged to estimate a sample-specific filter parameter and a channel estimate by interpolation.

27. A receiver according to claim 26, **characterized** in that the receiver is arranged to form an averaged autocorrelation corresponding to the combined preliminary channel estimate, and to decimate the averaged autocorrelations in order to form a filter parameter less often than at intervals of one received sample.

28. A receiver according to claim 27, **characterized** in that the receiver is arranged to decimate the averaged autocorrelations and, after decimation, to extrapolate the latest averaged autocorrelation from the previous averaged autocorrelations.

29. A receiver according to claim 18, **characterized** in that when the symbols in a control channel time slot are only partly pilot symbols (422, 428, 434, 440, 446, 452, 455, 502, 508, 514, 520, 526, 532, 538), the receiver is arranged to form at least one channel estimate per time slot by using the pilot symbols (422, 428, 434, 440, 446, 452, 455, 502, 508, 514, 520, 526, 532, 538) contained in the time slot, and to form sample-specific averaged channel estimates by interpolation.

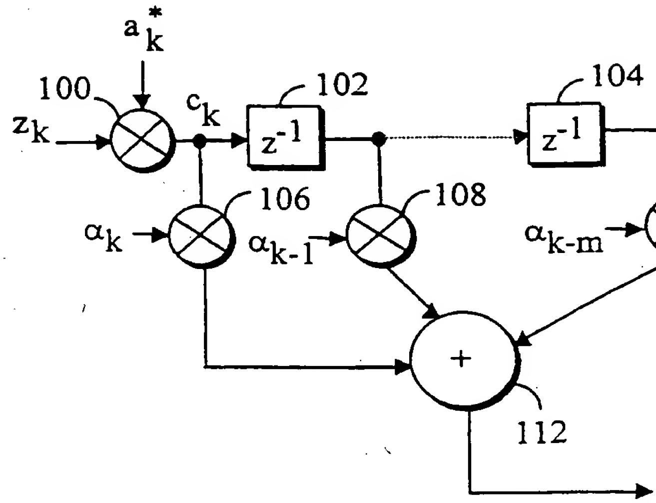
30. A receiver according to claim 18, **characterized** in that the receiver is arranged to form at least two non-sample-specific averaged channel estimates in each time slot.

31. A receiver according to claim 30, **characterized** in that when pilot symbols in a time slot form at least two symbol groups (600 - 626, 720 - 734) with difference distances in time from pilot symbol groups (600 - 626, 720 - 734) in the same and in an adjacent time slot, the receiver is arranged to form an average autocorrelation result of two successive averaged autocorrelations with different time distances, and the receiver is arranged to adjust the time distance of the average autocorrelation result to an average of the time distances of said two pilot groups.

32. A receiver according to claim 18, **characterized** in that the receiver is arranged to delay the processing of the received pilot signal by a predetermined time.

33. A receiver according to claim 32, **characterized** in that the receiver is arranged to delay the processing of the received signal by a predetermined number of time slots, and the receiver is arranged to form only the averaged channel estimates and the filter parameters that are later than/prior to the signal processing moment, and the receiver is arranged to form the filter parameters that are prior to/later than the signal processing moment as complex conjugates of the filter parameters that are later than/prior to than the signal processing moment.

34. A receiver according to claim 18, **characterized** in that the receiver is a RAKE receiver, which is arranged to form an average channel estimate for each multipath-propagated signal.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α_{k-m}
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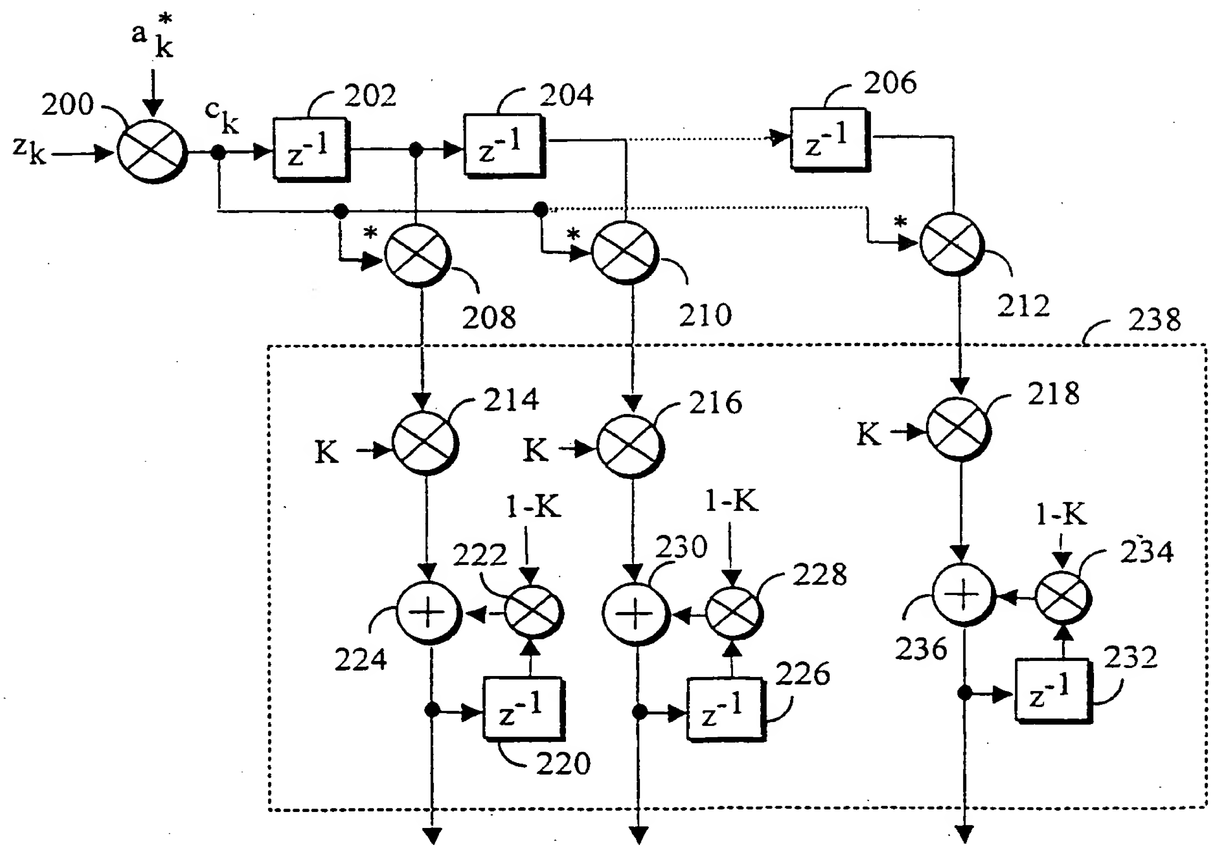
+
112

FIG. 1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238
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214
K
216
K
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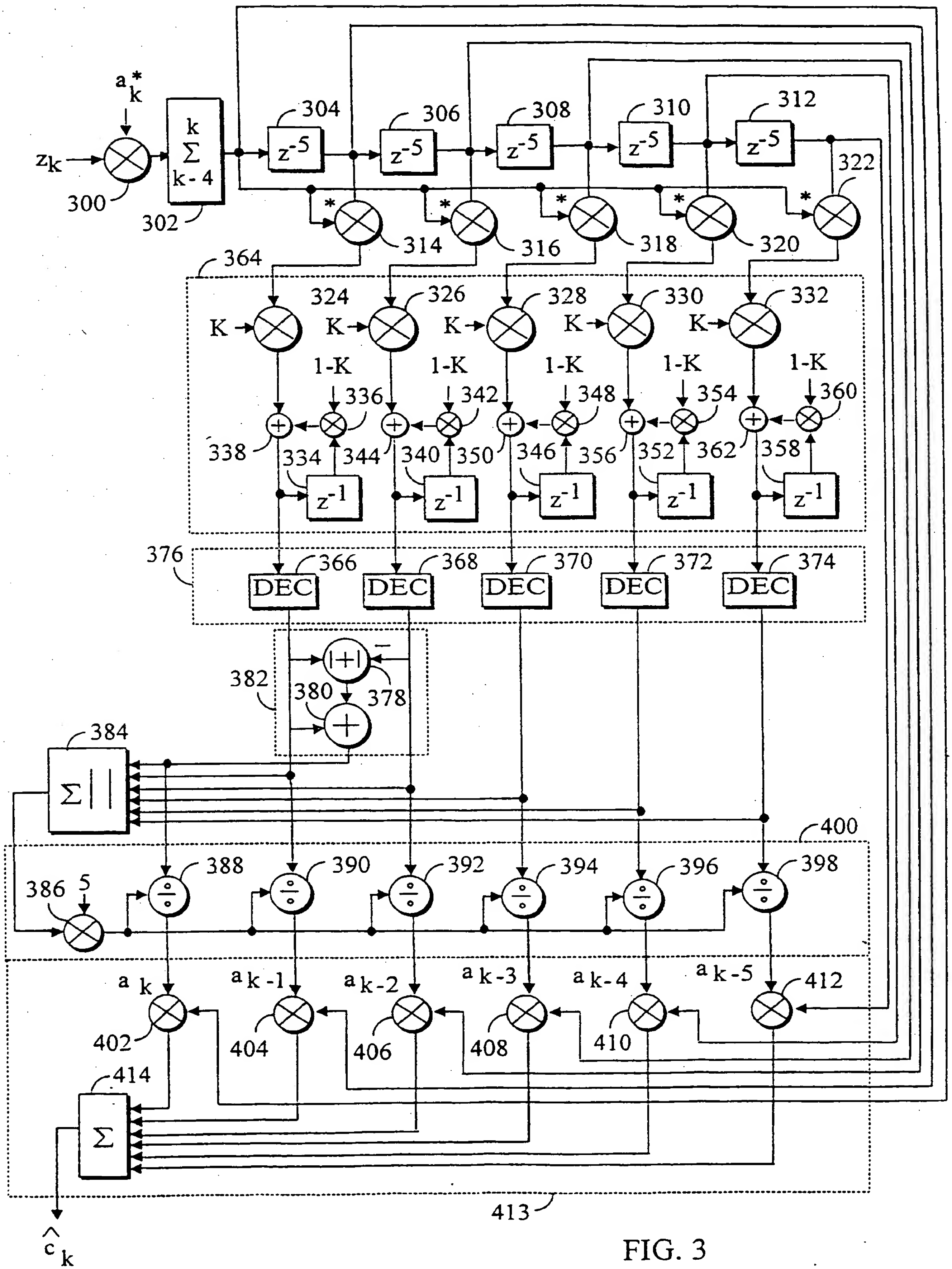
FIG. 2



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z_k
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302
$\sum_{k-4}^{k}$
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306
308
310
312
z^{-5}
314
316
318
320
322
364
324
326
328
330
332
K
1-K
336
342
348
354
360
338
334
344
340
350
346
356
352
362
358
z^{-1}
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366
368
370
372
374
DEC
382
380
378
384
386
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388
390
392
394
396
398
400
a_k
a_{k-1}
a_{k-2}
a_{k-3}
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a_{k-5}
402
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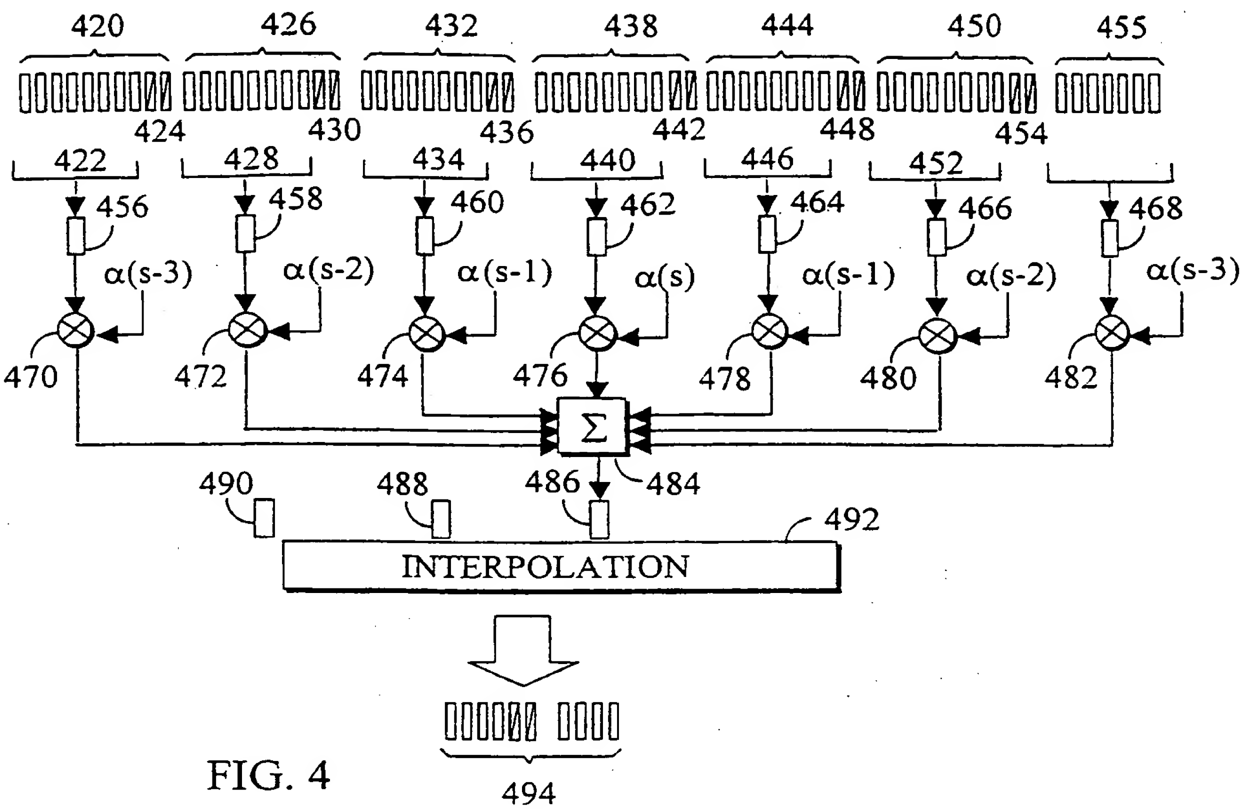
413
$\hat{c}_k$

FIG. 3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476
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Σ
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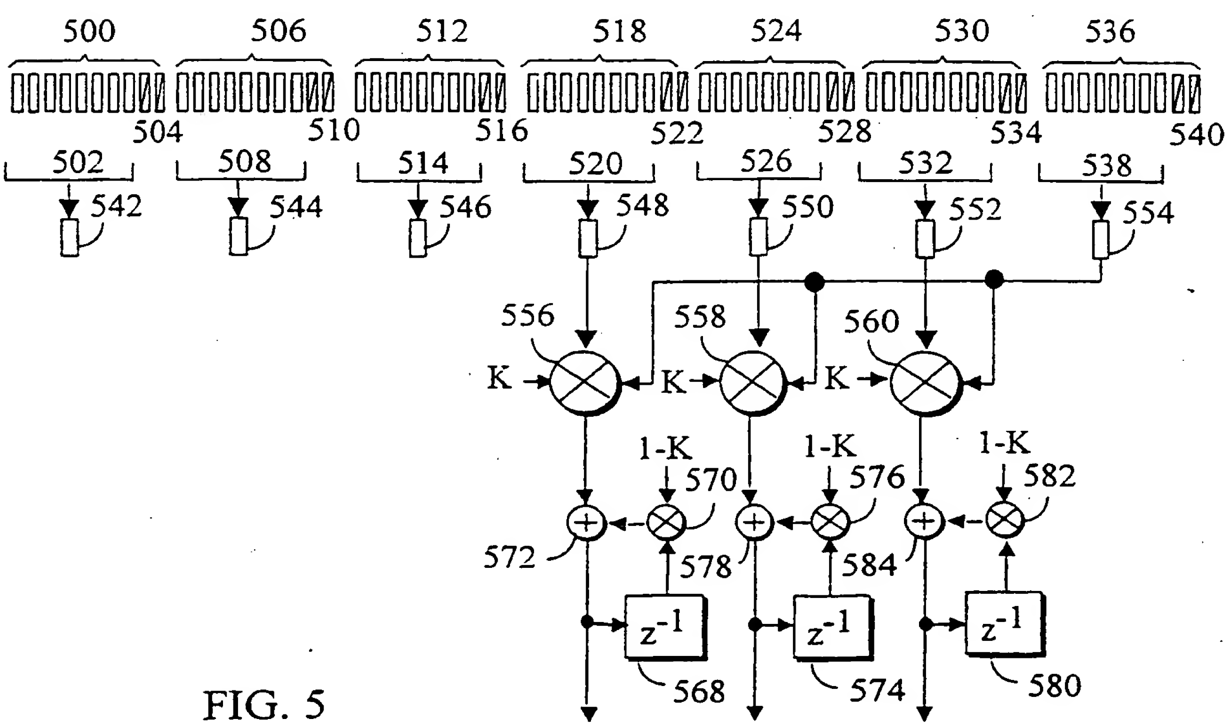
486
488
490
492
INTERPOLATION
494

FIG. 4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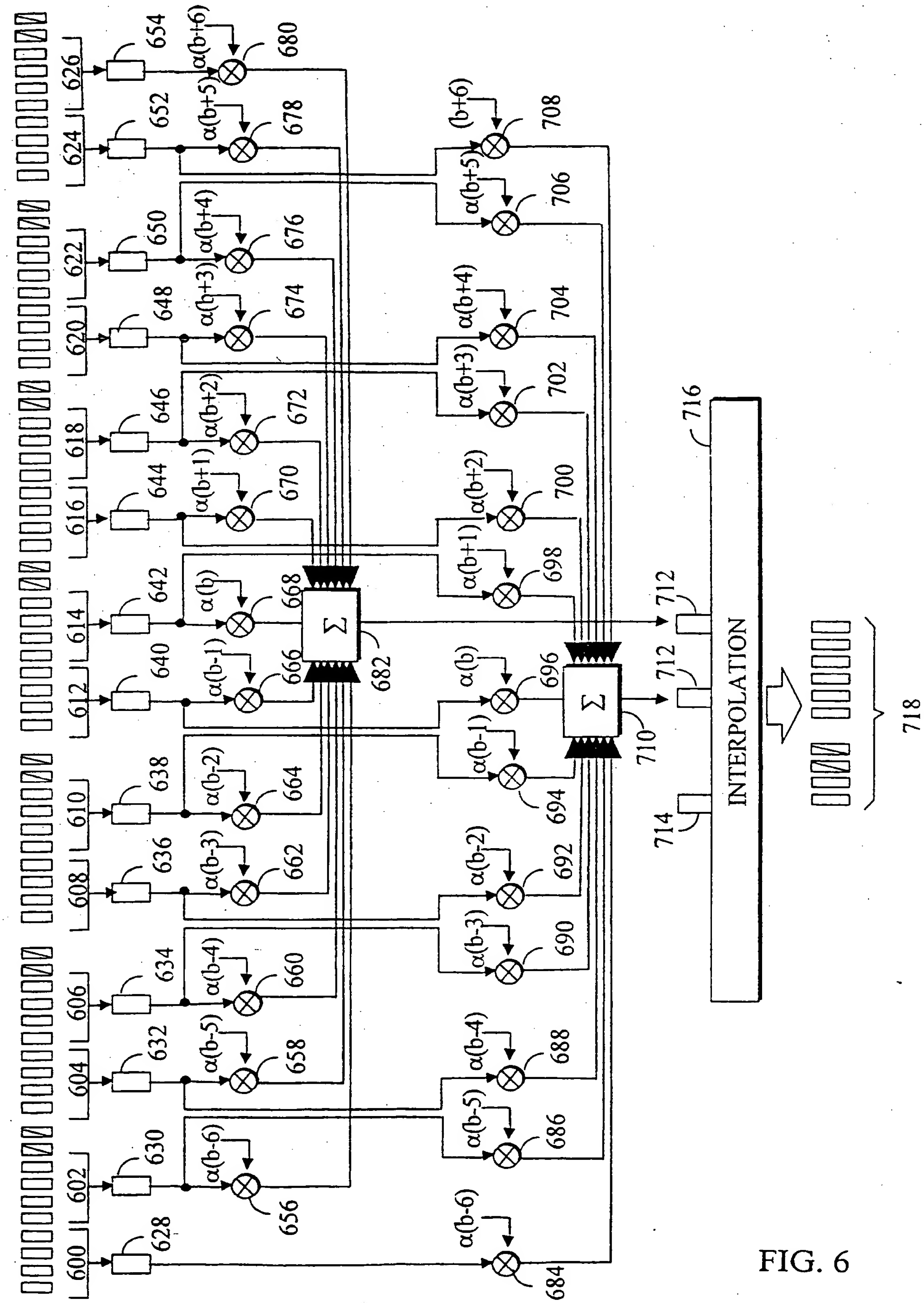
580

FIG. 5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650
652
654
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α(b+6)
(b+6)
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680
682
684
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688
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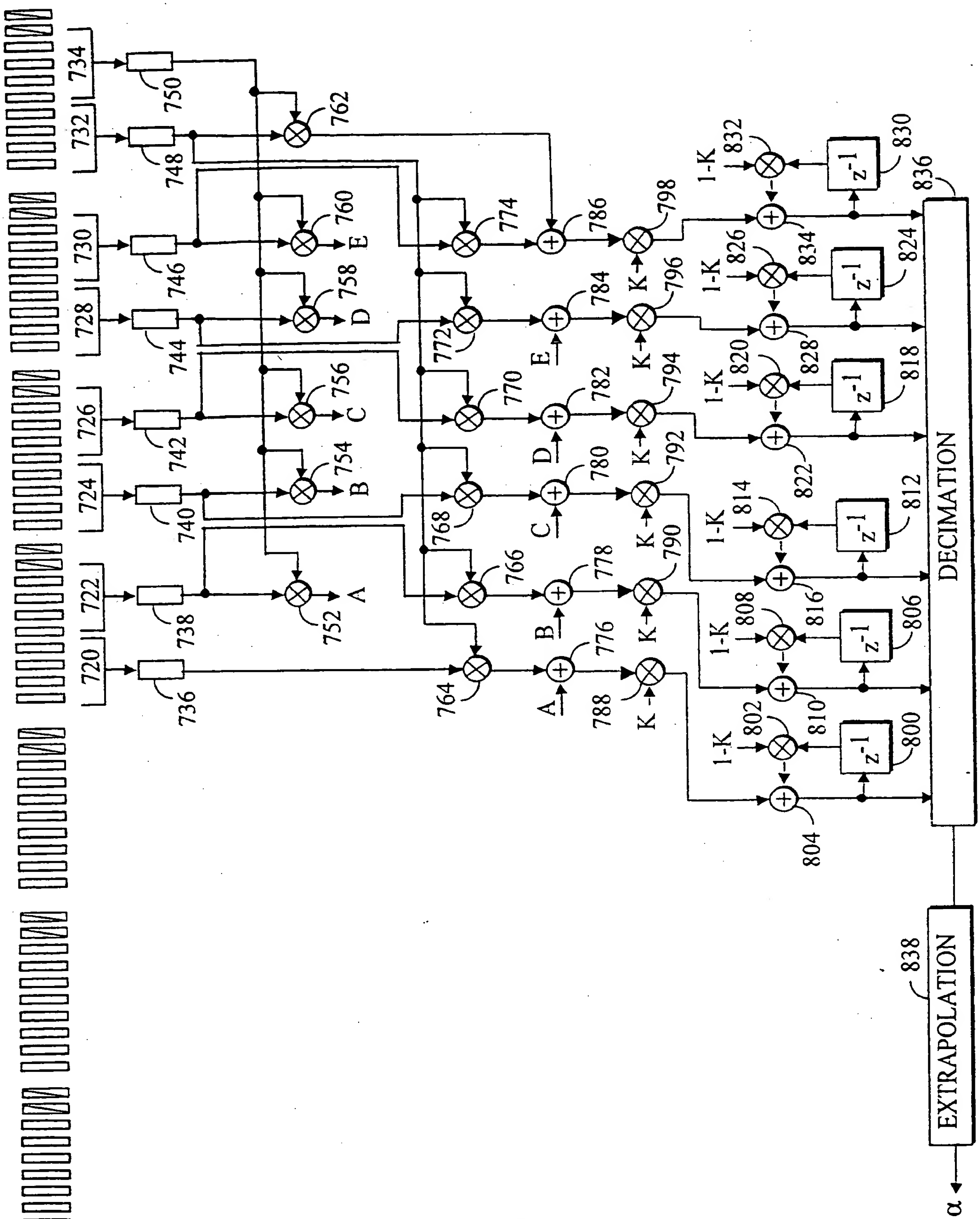
714
716
718
Σ
INTERPOLATION

FIG. 6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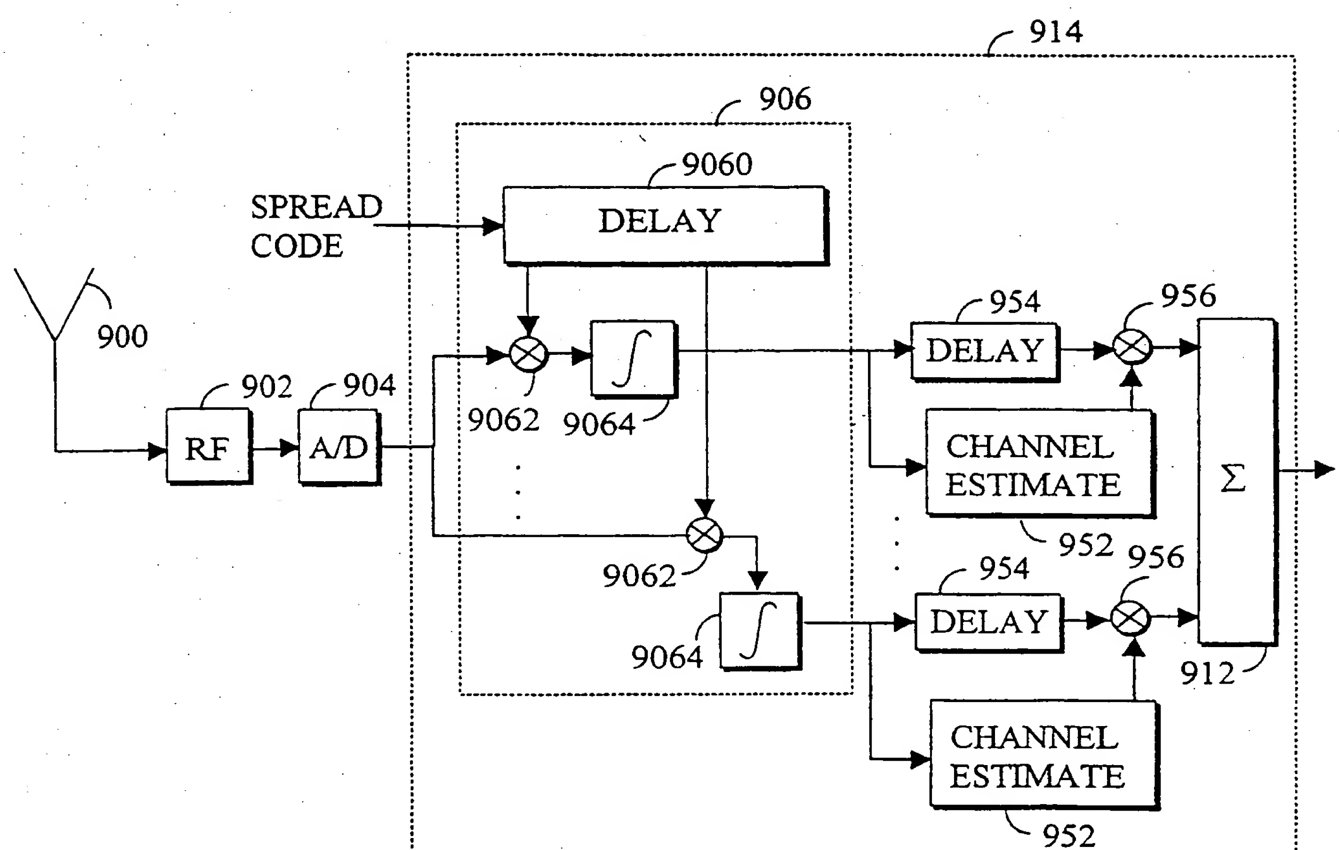
806
808
810
812
814
816
818
820
822
824
826
828
830
832
834
836
838
A
B
C
D
E
K
1-K
z^-1
DECIMATION
EXTRAPOLATION
α

FIG. 7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900
954
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DELAY
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904
RF
A/D
9062
9064
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Σ
952
956
9062
954
DELAY
9064
912
CHANNEL ESTIMATE
952

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 00/00369

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: H04B 1/76, H04J 13/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: H04B, H04L, H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5712877 A (PAUL K.M. HO ET AL), 27 January 1998 (27.01.98), column 19, line 29 - column 10, line 57, abstract --	1-34
P,A	IEICE TRANS. COMMUN., Volume E82-B, No 12, December 1999, T. ASAHARA, T. KOJIMA, M. MIYAKE, "An Improved Pilot Symbol Assisted Coherent Detection Scheme for Rician Fading Channels", page 2041 - page 2048, section 2.1-3.2 --	1-34

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" erlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 August 2000	16 -08- 2000

Name and mailing address of the ISA/	Authorized officer
Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Fredrik Blomqvist/mj Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 00/00369

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	"New Rayleigh fading channel estimator based on PSAM channel sounding technique" Young-Su Kim; Chang-Joo Kim; Goo-Young Jeong; Young-Jo Bang; Han-Kyu Park; Sang Sam Choi Communications, 1997. ICC'97 Montreol Towards the Knowledge Millenium. 1997 IEEE International Conference on 8-12 June 1997	1,18

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 00/00369

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5712877 A	27/01/98	NONE	

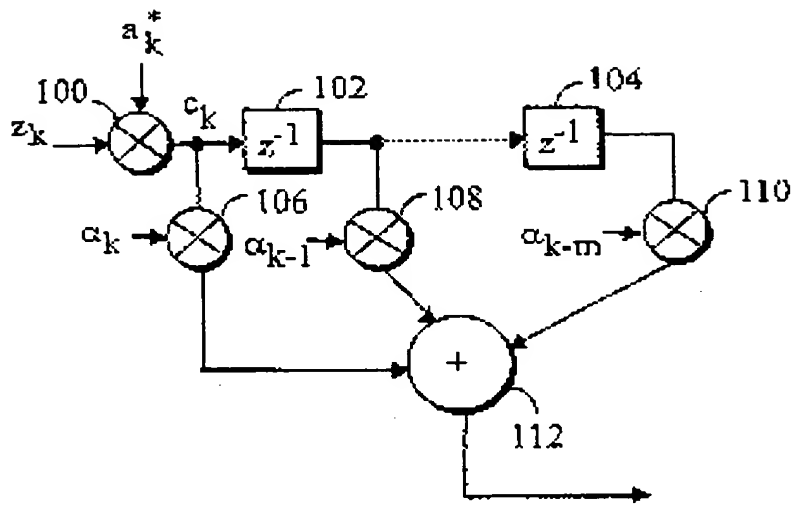

a_k^*
100
z_k
c_k
102
z^{-1}
104
z^{-1}
106
108
110
α_k
α_{k-1}
α_{k-m}
+
112

FIG. 1

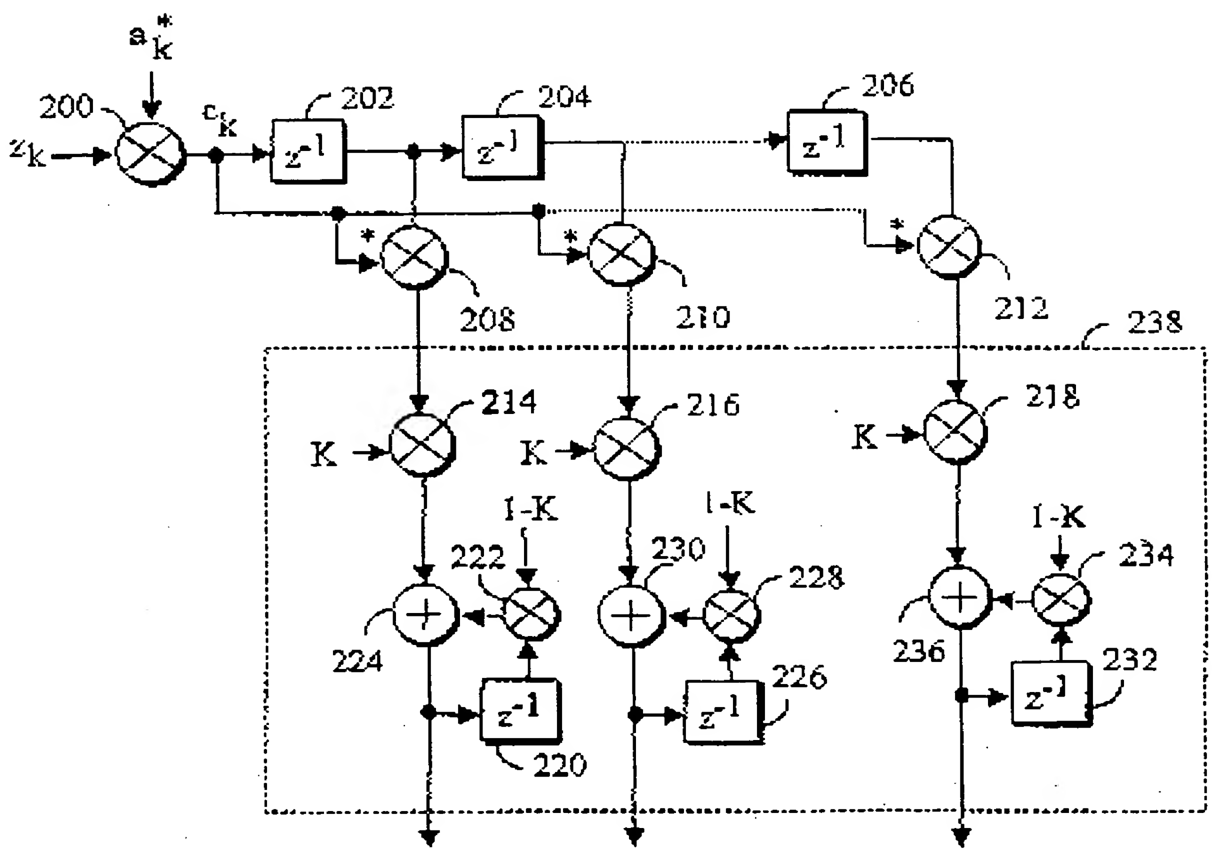

a_k^*
200
z_k
c_k
202
z^{-1}
204
z^{-1}
206
z^{-1}
*
*
*
208
210
212
238
214
216
218
K
K
K
1-K
1-K
1-K
222
230
228
234
224
236
226
232
220
z^{-1}
z^{-1}
z^{-1}

FIG. 2

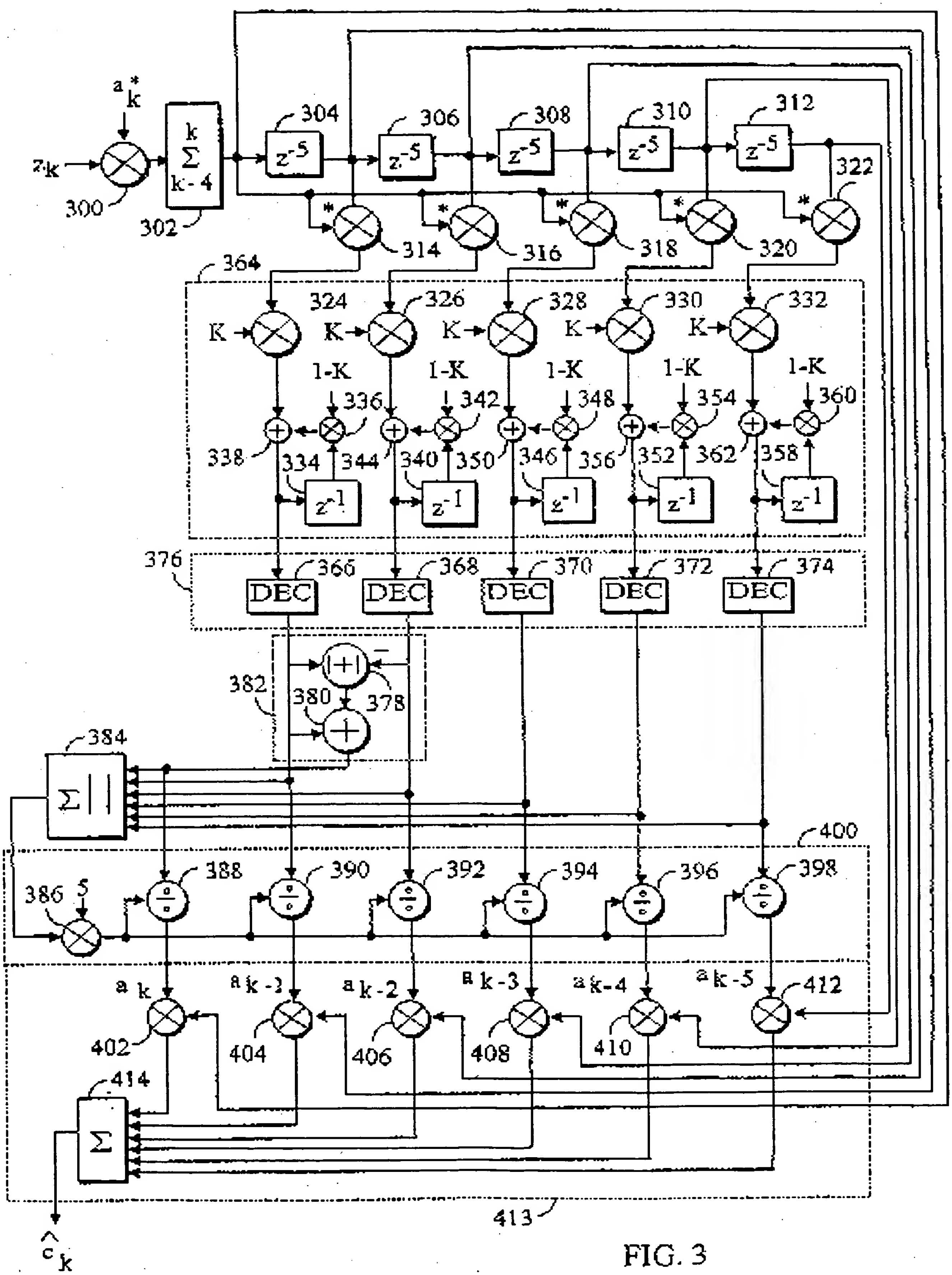

a^*_k
z_k
300
302
304
306
308
310
312
314
316
318
320
322
364
K
1-K
DEC
376
382
378
380
384
386
5
400
a_k
a_{k-1}
a_{k-2}
a_{k-3}
a_{k-4}
a_{k-5}
413
414
$\hat{c}_k$

FIG. 3

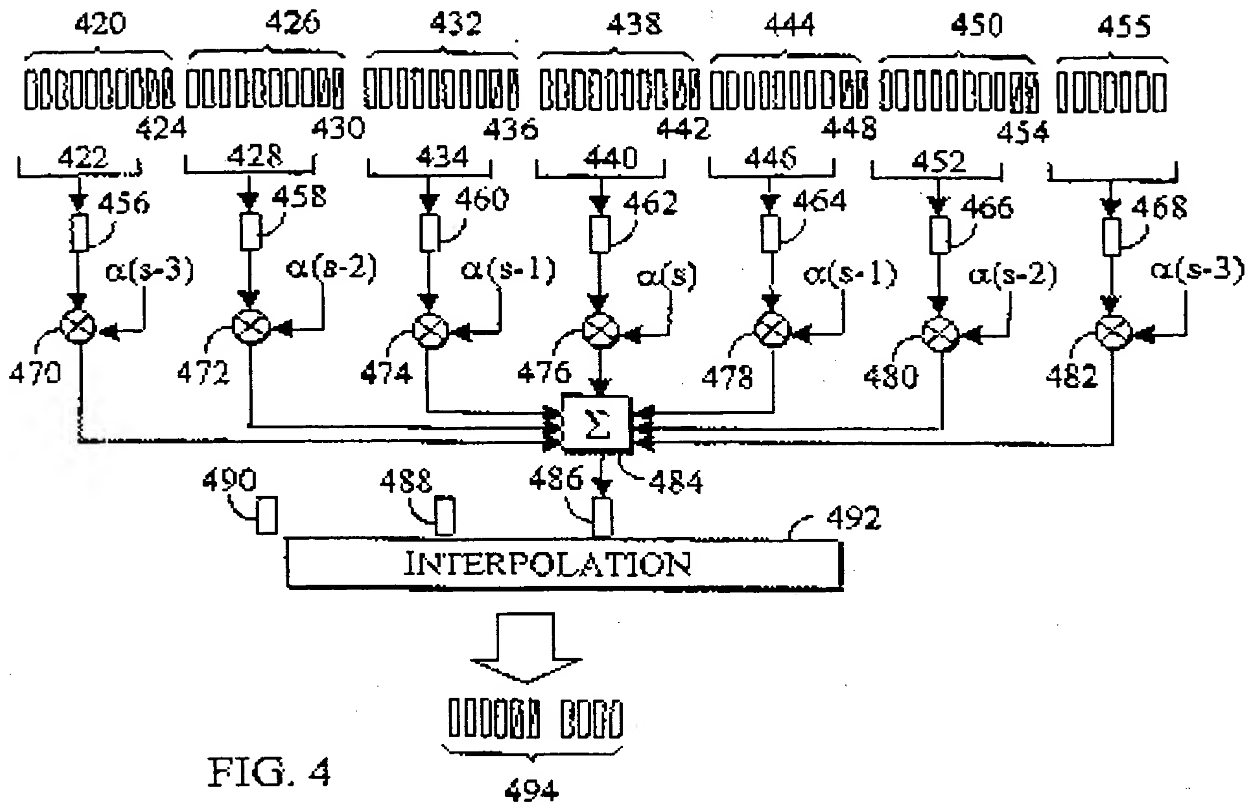
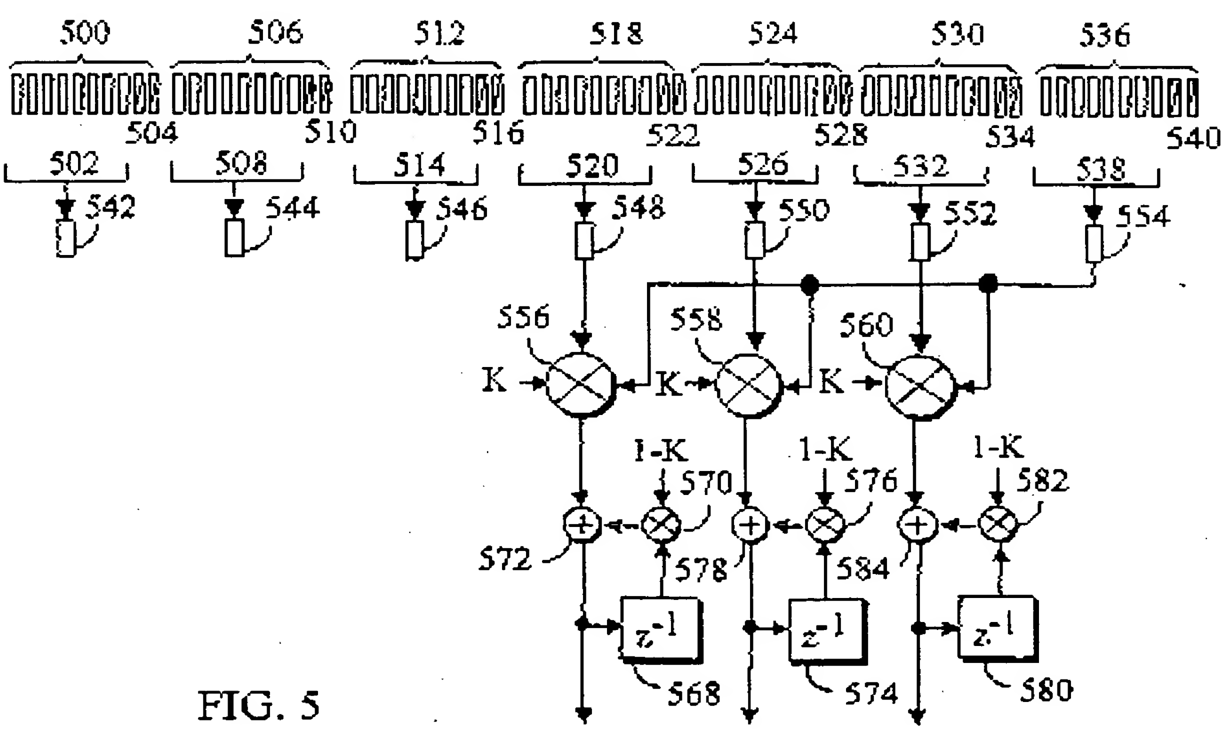

420
426
432
438
444
450
455
424
430
436
442
448
454
422
428
434
440
446
452
456
458
460
462
464
466
468
α(s-3)
α(s-2)
α(s-1)
α(s)
α(s-1)
α(s-2)
α(s-3)
470
472
474
476
478
480
482
Σ
490
488
486
484
492
INTERPOLATION
494

FIG. 4


500
506
512
518
524
530
536
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516
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526
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544
546
548
550
552
554
556
558
560
K
K
K
1-K
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570
576
582
572
578
584
z-1
z-1
z-1
568
574
580

FIG. 5

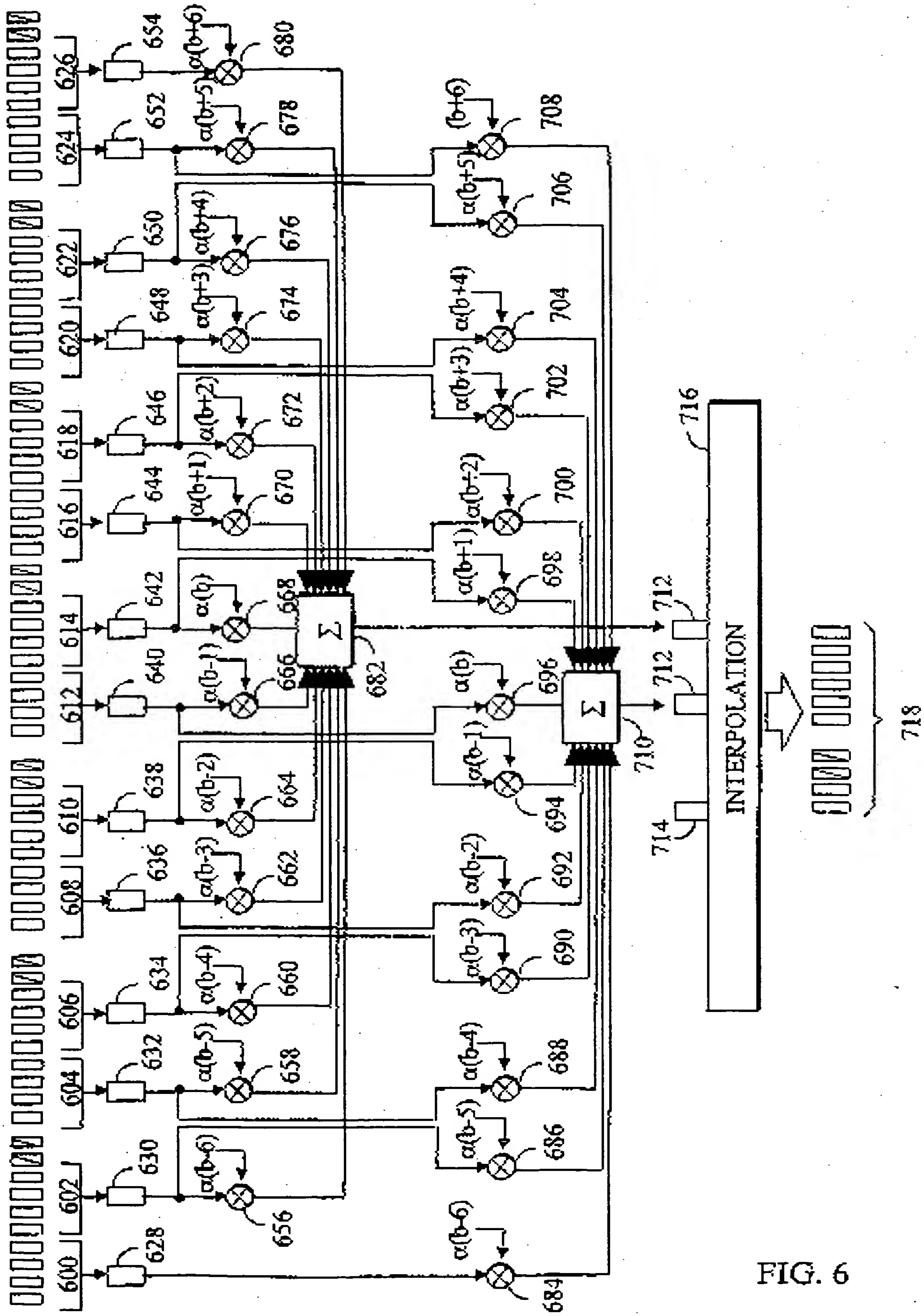

FIG. 6

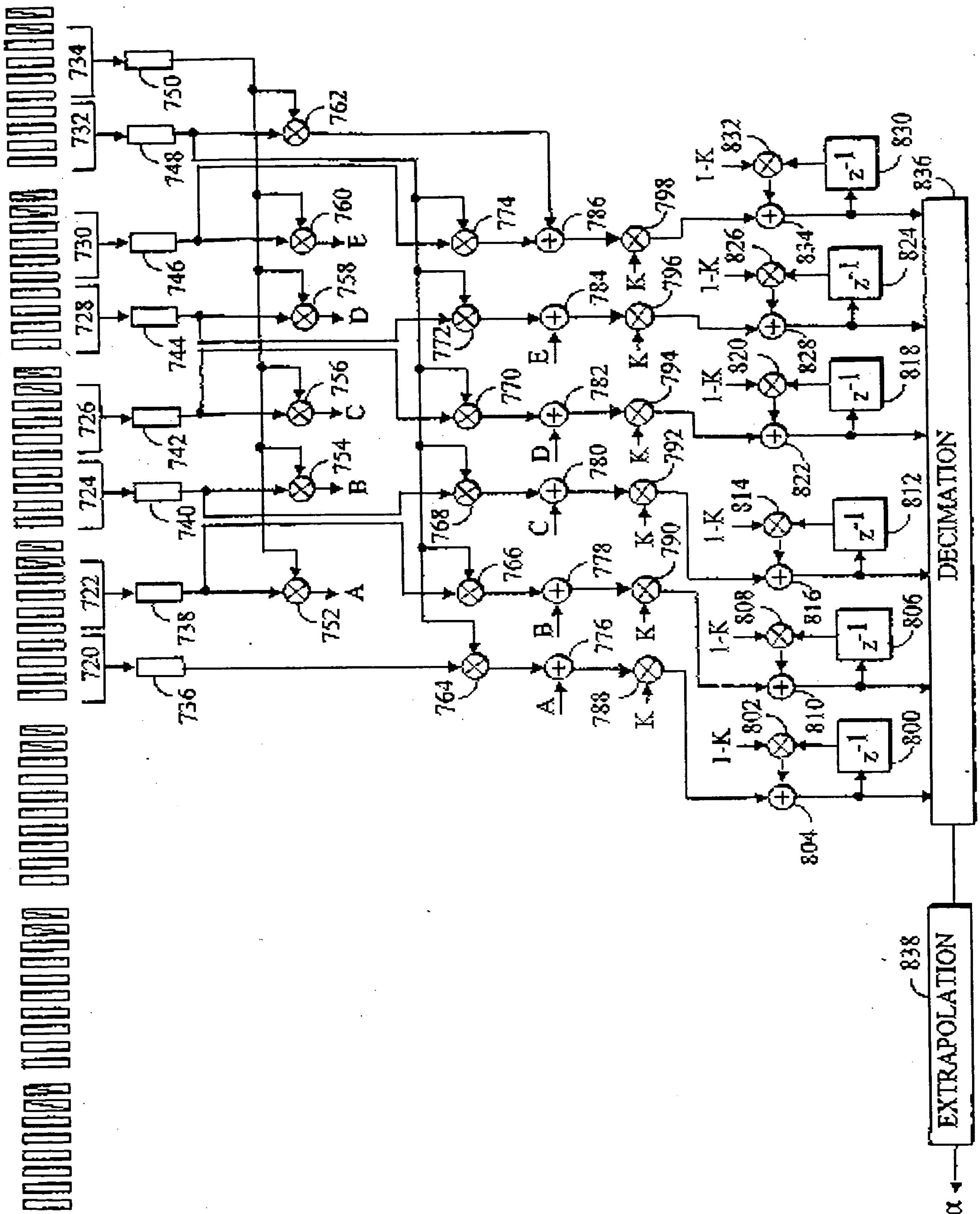

FIG. 7

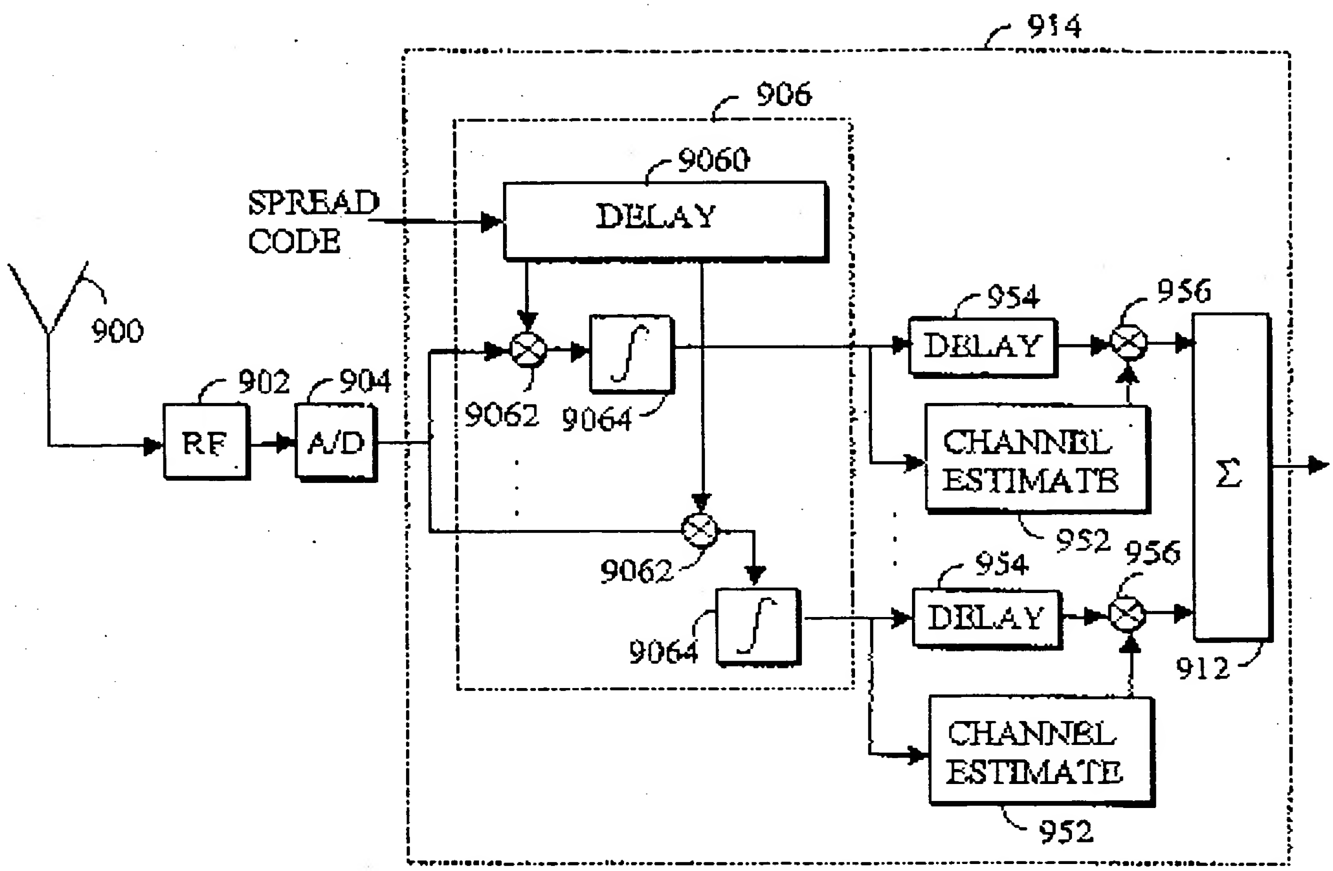
914
906
9060
SPREAD CODE
DELAY
900
902
904
RF
A/D
9062
9064
954
956
DELAY
CHANNEL ESTIMATE
952
Σ
9062
9064
954
956
DELAY
912
CHANNEL ESTIMATE
952

FIG. 8